Teaching Contextually

Research, Rationale, and Techniques for Improving Student Motivation and Achievement in Mathematics and Science

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ABSTRACT

Our nation's best mathematics and science teachers seem to have natural ability to motivate their students and engage them actively in the learning process. These teachers develop student understanding of fundamental concepts—not memorization of facts, definitions, and procedures—as the first priority. Many of the classroom strategies used by these teachers have also been shown by cognitive science and learning research to be the best methods to help students construct and use knowledge in mathematics and science. This report describes five of these strategies, called contextual teaching strategies:

- Relating – learning in the context of one's life experiences or preexisting knowledge
- Experiencing – learning by doing, or through exploration, discovery, and invention
- Applying – learning by putting the concepts to use
- Cooperating – learning in the context of sharing, responding, and communicating with other learners
- Transferring – using knowledge in a new context or novel situation—one that has not been covered in class

This report presents examples of the use of these strategies in mathematics classrooms. It also cites research studies and compendiums that document how the strategies can improve student motivation and achievement in mathematics and science.

CONTENTS

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". . . *The future well-being of our nation and people depends not just on how well we educate our children generally, but on how well we educate them in mathematics and science specifically.*"[1]

National Commission on Mathematics and Science Teaching for the 21st Century

The findings of the National Commission on Mathematics and Science Teaching for the 21st Century reflect what parents and employers have been saying for many years. Mathematics and science education is crucial. Unfortunately, it is not up to the standards needed. In reaction to our children's poor performance on the Third International Mathematics and Science Study (TIMSS) and the National Assessment of Educational Progress (NAEP), the commission stated, ". . . It is abundantly clear . . . that we are not doing the job that we should do—or can do—in teaching our children to understand and use ideas from these fields. Our children are falling behind; they are simply not 'world-class learners' when it comes to mathematics and science."[2]

Teaching methods used by the vast majority of teachers that may have worked well enough for past generations are not working well enough today. We need to change educational strategies, and the place to begin is in the classroom: ". . . After an extensive, in-depth review of what is happening in our classrooms, the Commission has concluded that the most powerful instrument for change, and therefore the place to begin, lies at the very core of education—*with teaching itself*."[3]

Can teachers change what they do in the classroom in such a way that their students' understanding and abilities to use mathematics and science improve? At CORD we believe the answer is yes, but only if teachers first make a fundamental change—a change in their primary goals in the classroom. Today, the goals of the majority of teachers are to cover the curriculum and meet the needs of an assessment. The Commission's findings have shown that teaching strategies for these goals have failed to produce "world-class learners." We believe that learning can be significantly improved only if the teacher's primary goal is to develop a deep sense of understanding of the fundamental concepts in the curriculum. In this report, we will present strategies that help develop these understandings. We call them *contextual teaching strategies*. They are based on research on how people learn for understanding and on observation of how the best teachers teach for understanding.

Constructivism

Before presenting the strategies, we will briefly discuss the modern view of learning—established by John Dewey, Jean Piaget, and Lev Vygotsky—called *constructivism*. Education researchers, psychologists, and cognitive scientists have published hundreds, perhaps thousands, of research articles about various aspects of constructivism. Fortunately for teachers and curriculum developers, several authoritative sources have summarized and generalized the most relevant research. For example, in 1999 the National Academy Press published *How People Learn: Brain, Mind, Experience, and School*—the result of a two-year project in which the country's leading educational researchers evaluated the latest developments in the science of learning. They defined constructivism as follows: "In the most general sense, the contemporary view of learning is that people construct new knowledge and understandings based on what they already know and believe."[4]

J. Lynn McBrien and Ronald S. Brandt, in *The Language of Learning: A Guide to Education Terms*, describe constructivism as "an approach to teaching based on research about how people learn. Many researchers say that each individual 'constructs' knowledge instead of receiving it from others."[5] They also describe teaching strategies that are based on the belief that students learn best when they gain knowledge through exploration and active learning. These strategies include using hands-on activities, encouraging students to think and explain their reasoning instead of merely memorizing and reciting facts, and helping students to see the connections among themes and concepts rather than presenting them in isolation.

Teachers can use constructivism to teach the way people learn best—but how? How does a "constructivist" classroom differ from a traditional classroom? Simply stated, teachers in constructivist classrooms engage students actively in the learning process. In these classrooms, students are more likely to discuss with other students their strategies for solving a problem instead of having the right strategy told to them by the teacher. They are more likely to be working cooperatively in small groups as they shape and reformulate their conceptions, rather than practicing skills silently at their seats. They are more likely to be engaged in hands-on activities than listening to lectures. In constructivist classrooms, teachers establish in students a sense of interest and confidence and a need for understanding.

In our years of teaching, supervising, and developing curricula, we at CORD have observed many outstanding teachers creating these classroom environments. These are award-winning teachers, teachers who succeed with students others have given up on, teachers whom parents want for their children, and teachers who make a difference in students' lives. Although many of them are unaware of cognitive science research findings and do not know the definition, their classrooms were and are models of constructivism. Each of these teachers is unique, and each uses diverse methods in the classroom. But we have observed five teaching strategies used by all these teachers, at least some of the time. We call them *contextual teaching strategies*: relating, experiencing, applying, cooperating, and transferring.[6] These strategies focus on teaching and learning in context—a fundamental principle of constructivism. REACT is an easily remembered acronym that represents methods used by the best teachers and also methods supported by research on how people learn best.

R*elating*
E*xperiencing*
A*pplying*
C*ooperating*
T*ransferring*

The remainder of this report will discuss each strategy in detail, as well as examples from mathematics teachers and instructional materials. (Mathematics was chosen because the author has spent most of the last five years reading and writing about mathematics and working with math teachers.) Research from cognitive science that supports each strategy will also be discussed.

RELATING

Relating is the most powerful contextual teaching strategy. It is also at the heart of constructivism. Relating is *learning in the context of one's life experiences or preexisting knowledge*.

Teachers use relating when they link a new concept to something completely familiar to students, thus connecting what students already know to the new information. When the link is successful, students gain almost instant insight. Caine and Caine call this reaction "felt meaning" because of the "aha!" sensation that often accompanies the insight.[7] Felt meaning can be momentous, as when a student first sees the solution to a problem that he or she has spent significant time and effort in solving. Felt meaning can also be subtle, as when insight leads to a milder reaction, such as, "Oh, that makes sense."

Excellent teachers plan carefully for learning situations in which students can experience felt meaning. Careful planning is needed because often students do not automatically connect new information to the familiar. Research shows that, although students may bring memories or prior knowledge that is relevant to a new learning situation, they can fail to recognize its relevance.[8] When teachers both provide environments in which students activate memories or prior knowledge *and* recognize the relevance of the memories or knowledge, they are using relating.

As an example, consider a mathematics lesson on ratio and proportion. A traditional approach typically begins with a definition, followed by an example:

Definition: A ratio is a comparison of two numbers by division.

Example: Suppose that a bag contains five marbles. Three of the five marbles are blue. The numbers 3 and 5 form a ratio, which can be written in three ways:

$$3 \text{ to } 5 \quad 3:5 \quad \frac{3}{5}$$

A teacher using relating could begin the lesson by asking questions that almost every student can answer from life experiences outside the classroom: "Have you ever made fruit punch from frozen concentrate? What did the instructions say?" The teacher then reinforces the students' prior knowledge by reading the instructions from a real container.

When a teacher relates this familiar experience to the definition of ratio, students can immediately see the relevance of their prior knowledge. Most students feel that they already know about ratio, or that the concept of ratio is accessible, because they are familiar with the experience of making fruit punch. They are also more likely to remember the definition of ratio because they can relate it to the fruit punch instructions.

> "What students learn is influenced by their existing ideas. People have to construct their own meaning regardless of how clearly teachers or books tell them things. Mostly, a person does this by connecting new information and concepts to what he or she already believes."[9]
>
> "Sound teaching usually begins with questions and phenomena that are interesting and familiar to students, not with abstractions or phenomena outside their range of perception, understanding, or knowledge."[10]
>
> American Association for the Advancement of Science, Project 2061

Research shows that learning is enhanced when teachers use relating, especially at the beginning of instruction with students' prior knowledge and beliefs as a starting point, and then adjust teaching in response to students' changing conceptions during instruction.[11] But how do teachers know, or discover, their students' prior knowledge and beliefs? There are three primary sources of this information.[12]

(1) Experience – from the teacher's own experience with students of similar backgrounds or from the collective experience of the teacher and his or her colleagues
(2) Research – from documented evidence of students' commonly held ideas
(3) Probes – from carefully designed questions or tasks that reveal students' prior knowledge and beliefs

> "Because students learn by connecting new ideas to prior knowledge, teachers must understand what their students already know. Effective teachers know how to ask questions and plan lessons that reveal students' prior knowledge; they can then design experiences and lessons that respond to, and build on, this knowledge."[13]
>
> National Council of Teachers of Mathematics

Students' prior knowledge and beliefs can serve as a foundation upon which new knowledge can be built. But prior knowledge can also be an impediment, especially in science.[14] Sometimes probing questions reveal incorrect, incomplete, or naïve understanding. These prior misconceptions can be especially difficult to overcome. Without careful instruction, students can construct a perfectly reasonable (for them) interpretation of new information while deeply misunderstanding the information.[15] When this happens, the misconceptions are reinforced and become part of a faulty foundation for constructing new information.

In contrast, careful instruction can provide opportunities for students to collect experimental evidence. Experiential learning is a means for students to confront misconceptions and also construct new knowledge. This is the second contextual teaching strategy.

EXPERIENCING

Relating connects new information to life experiences or prior knowledge that students bring with them to the classroom. But this approach is not possible if students do not have relevant experience or prior knowledge. Teachers can overcome this obstacle and help students construct new knowledge with orchestrated, hands-on experiences that take place inside the classroom. This strategy is called *experiencing*. It is *learning by doing—through exploration, discovery, and invention*. In-class hands-on experiences can include the use of manipulatives, problem-solving activities, and laboratories.

Manipulatives. These are simple objects that students can move around to model abstract concepts concretely. For example, in mathematics, base-ten blocks model numeric representation in the decimal system. Fraction bars demonstrate the meaning of simple fractions and addition and multiplication of fractions. Area tiles model multiplication of polynomials. Some computer programs, such as *Geometer's Sketchpad*© and *Cabri*©, can be considered manipulatives since they enable students to visualize and explore concepts and to quickly see answers to "what if ? " questions. Manipulatives have been shown to enhance student performance when they are coherently integrated into the curriculum.[16]

> From an analysis of 1996 NAEP test data for two national samples of approximately 15,000 8th grade students:
>
> "Students whose teachers conduct hands-on learning activities outperformed their peers by more than 70% of a grade level in math and 40% of a grade level in science."[17]
>
> Harold Wenglinsky

Problem-solving activities. These are learning experiences that engage students' creativity while they are learning key concepts. These activities also teach problem-solving skills, analytical thinking, communication, and group interaction.

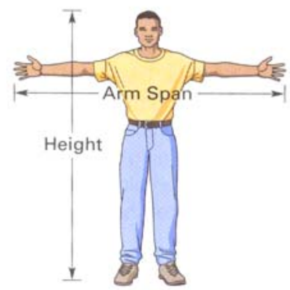
The best problem-solving activities introduce key concepts—usually curriculum objectives or standards—as they arise naturally in problem situations. This allows students to see a need or a reason for using the new concepts. When they see relevant uses of knowledge in solving interesting problems, students can make sense of what they are learning.[18] This has been shown to motivate students to exert the required effort to gain and use the new knowledge.[19]

An example of this kind of problem-solving activity is a continuation of the lesson on ratio and proportion. After introducing the concept of ratio using relating and the instructions for making fruit punch, the teacher poses a problem: "How many cans of concentrate and how many cans of water are needed to make fruit punch for the whole class?" Students working individually or in groups are likely to try several different problem-solving approaches and have different solutions, because answers depend on students' assumptions. (How much punch is needed? How can we make sure we use the same 3 : 1 ratio of water to concentrate?) Relevance and motivation can be enhanced if students know that at the end of the lesson they will, as a class, decide on a single best solution and then actually make the fruit punch to "check their answer."

This activity can create motivation for the need to know about and use ratio and proportion, but students are very unlikely to discover the key mathematical concepts on their own. The teacher must be prepared to facilitate student discussion and problem solving, summarize students' approaches and results, and demonstrate and generalize the concept at the right time. In mathematics, definitions and solution procedures are part of this generalization. Generalizing the specific experience or information is a key step in learning. Research shows that students have a greater ability to use new knowledge in multiple contexts, beyond those covered in class, when the teacher (or, if possible, the student) generalizes key information after the student uses the information or experience in a specific context.[20] The ability to use new knowledge in novel situations is called *transferring*, and we will discuss it more later as a separate contextual teaching and learning strategy.

Laboratory activities and projects. These are usually longer and require more planning than problem-solving activities. In a laboratory, students work in small groups to collect data by making measurements, analyze the data, make conclusions and predictions, and reflect on the fundamental concepts involved in the activity.

Students can be involved in laboratory activities even in mathematics classes. For example, in one classic activity students in groups measure their heights and arm spans. They combine their group data with the rest of the class and display the class data in a chart. A chart is one way to represent the data. The students then make a coordinate axis system and plot the (height, arm span) ordered pairs.



The plot is another way to represent the data. From the plot, students will notice a pattern and a relationship between students' heights and arm spans. Using the plotted data, students can draw a line of best fit. Then students can discover the power and utility of correlation by measuring their teacher's arm span and using the fitted line (either the equation of the line or the graph or both) to predict the teacher's height.

This activity teaches different ways to represent data, patterns, and ordered pairs; how to plot ordered pairs on a coordinate plane; how to draw a line of best fit; and how to use linear correlations between two variables. By using their own data, students are more likely to generate interest in creating models to represent and understand relationships, and therefore to develop a sense of understanding, or felt meaning, for these concepts.[21]

"Progression in learning is usually from the concrete to the abstract. Young people can learn most readily about things that are tangible and directly accessible to their senses—visual, auditory, tactile, and kinesthetic. With experience, they grow in their ability to understand abstract concepts, manipulate symbols, reason logically, and generalize. These skills develop slowly, however, and the dependence of most people on concrete examples of new ideas persists throughout life."[22]

American Association for the Advancement of Science

It is important to note that neither experiential learning—the use of manipulatives, problem-solving activities, and laboratory activities—nor constructivism in general implies that teachers should never tell students anything directly, but should instead allow students to discover knowledge for themselves.[23] In fact, teachers must orchestrate these experiences because, while students often know how to make measurements, they usually do not know what measurements to make or when to make them.[24] Research shows that guided discovery and "scaffolded" inquiry are much more effective for learning than open-ended discovery.[25] Scaffolding is support provided by a teacher to make sure students succeed at a complex task they couldn't do otherwise. Students learn as they go about the task, rather than before they start.

Simply assigning reading and providing lectures represents one end of a continuum of teaching strategies. Teachers who only lecture maintain total control of the learning environment. Open-ended discovery represents the other end of the continuum. At this extreme, students have total control of the environment. Research shows that consistently working at one of these extremes is not effective for many students—the best strategy lies somewhere in the middle, using relating and experiencing to prepare students for lecture and reading.[26]

> "When telling occurs without readiness, the primary recourse for students is to treat the new information as ends to be memorized rather than as tools to help them perceive and think."[27]
>
> Daniel L. Schwartz and John D. Bransford

Relating and experiencing are two strategies for enhancing student ability to learn new concepts. But knowing when and how to integrate these strategies in instruction is not simple. Teachers need research, collaboration, and excellent instructional materials to know when to activate familiar experiences and prior knowledge, when to design and orchestrate activities that help students construct new knowledge for themselves, and when it is best to lecture or assign reading.

APPLYING

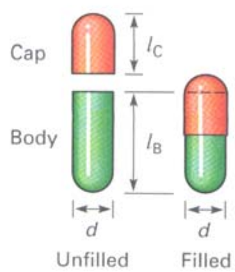
We define the *applying* strategy as *learning by putting the concepts to use*. Obviously, students apply concepts when they are engaged in hands-on problem-solving activities and projects like those described above. Teachers also can motivate a need for understanding the concepts by assigning *realistic* and *relevant* exercises.

These exercises are "word problems" like those found in all textbooks. But they have two major differences: They pose very realistic situations, and they demonstrate the utility of academic concepts in some area of a person's life. Both are important for application problems to be motivational. For example, the following is a typical word problem from a geometry lesson on volume of solids. It may be "real world," but, after assigning this problem, how would you answer a student asking, "So what?"

> A hemispherical plastic dome covers an indoor swimming pool. If the diameter of the dome measures 150 feet, find the volume enclosed by the dome in cubic yards.

The intent of the problem is to have students recall and use the formula for the equation of the volume of a sphere. The problem statement below also requires students to recall and use this formula. But in this problem, the formula and calculation are crucial in a believable decision-making situation. This problem inherently answers, "So what?"

> Montgomery is a pharmacist at a pharmaceutical manufacturing plant. He is responsible for selecting the correct capsule sizes for the company's products. The capsule size determines the dosage. The company uses eight sizes. The body length l_B, cap length l_C, and diameter d of the capsules are shown in the table.



Capsule Size	Body Length (mm)	Cap Length (mm)	Diameter (mm)
000	22.96	13.44	9.52
00	20.50	12.00	8.50
0	18.86	11.04	7.82
1	16.51	9.65	6.86
2	15.35	9.10	6.25
3	13.60	8.13	5.47
4	12.30	7.20	5.10
5	9.84	5.76	4.08

> Montgomery must select a capsule size for production of a 25-milligram dosage of an antidepressant. Each capsule must contain 650 ± 10 mm^3 of the compound. Which size capsule should Montgomery select?

All students will see the importance of the key concepts in solving this realistic problem. But not all students aspire to become pharmacists. So other problems could be assigned that cover diverse situations. In working exercises throughout the school year, students should find realistic scenarios that are applicable to their current or possible future lives outside the classroom (e.g., as consumers, family members, recreationists, sports competitors, workers, and citizens).

> "If (students) practice only calculating answers to predictable exercises or unrealistic 'word problems,' then that is all they are likely to learn." [28]
>
> American Association for the Advancement of Science
> Project 2061

Research shows that realistic or authentic exercises can motivate students to learn academic concepts at a deeper level of understanding. Recommended classroom strategies from research include:

- "*Focus on meaningful aspects of learning activities.* Teachers should stress how the academic tasks that are done in the classroom are relevant and 'authentic' tasks that have meaning in the real world."[29]
- "*Design tasks for novelty, variety, diversity, and interest*. Teachers should attempt to provide a wide variety of tasks for students to engage in and ensure that the tasks have some novel, interesting, or surprising features that will engage the students."[30]
- "*Design tasks that are challenging but reasonable in terms of students' capabilities*."[31]

The last strategy is important in the constructivist view of learning. If a task is too easy, students can become bored, or convinced they have already mastered the required material, and lose motivation for learning new concepts. If a task is too difficult, students cannot make significant progress, and they can become convinced they are incapable of mastering the concepts. A task that is in-between, "challenging but reasonable," is one in which students can make legitimate progress while constructing (or reinforcing) new knowledge. Vygotsky described this kind of task as being in the "zone of proximal development."[32]

> "As far as the nature of the curriculum and tasks is concerned, Maehr & Midgley (1991) suggest that a mastery-oriented school will focus the curriculum and academic tasks in such a way to foster student value and interest in learning, rather than merely provide coverage of the curriculum to meet assessment or bureaucratic needs. This can be done by encouraging the use of authentic tasks and meaningful activities that link the content of the curriculum to real-world problems and to the backgrounds and experiences of the students. These tasks also should be challenging to students, but not beyond their level of competence."[33]
>
> Paul R. Pintrich and Dale H. Schunk

Relating and experiencing are strategies for developing insight, felt meaning, and understanding. These insights are empowering—they foster an attitude in students that "I *can* learn this." Applying is a contextual teaching and learning strategy that develops a deeper sense of meaning—a reason for learning. This strategy fosters a second attitude that "I *need* or *want* to learn this." Together, these attitudes are highly motivational.

COOPERATING

Many problem-solving exercises, especially when they involve realistic situations, are complex. Students working individually sometimes cannot make significant progress in a class period on these problems. They can become frustrated unless the teacher provides step-by-step guidance. On the other hand, students working in small groups can often handle these complex problems with little outside help.[35] Teachers using student-led groups to complete exercises or hands-on activities are using the strategy of *cooperating—learning in the context of sharing, responding, and communicating with other learners*.

Working with their peers in small groups, most students feel less self-conscious and can ask questions without feeling embarrassed. They also will more readily explain their understanding of concepts to others or recommend problem-solving approaches for the group. By listening to others in the group, students reevaluate and reformulate their own sense of understanding. They learn to value the opinions of others because sometimes a different strategy proves to be a better approach to the problem. When a group succeeds in reaching a common goal, student members of the group experience higher self-confidence and motivation than when students work alone.[36]

> "Learning often takes place best when students have opportunities to express ideas and get feedback from their peers."[37]
>
> American Association for the Advancement of Science, Project 2061

Hands-on activities and laboratories are best done, and sometimes must be done, in groups. Many teachers assign student roles for these activities, such as equipment custodian, timer, measurer, recorder, evaluator, and observer. Roles instill a sense of identity and responsibility and become very important as students realize that successful completion of an activity depends on every group member doing his or her job.[38] Success also depends on other group processes—communication, observation, suggestion, discussion, analysis, and reflection. These processes are themselves important learning experiences.

Many research studies show that cooperative or collaborative learning promotes higher student achievement than traditional individualistic and competitive methods.[39] But greater understanding of academic concepts is not the result of simply placing students in groups and telling them to work together. In fact, some efforts at using cooperative learning can be counterproductive. For example, some students may not participate in the group processes at all, while others may dominate; group members may refuse to accept or share responsibility for the group's work; the group may be too dependent on the teacher for guidance; or the group can be sidetracked by conflict. Two of the leading researchers in cooperative learning, David Johnson and Roger Johnson, have established guidelines to help teachers avoid these negative conditions and create environments in which students may be expected to learn concepts at a deeper level of understanding.[40] These guidelines include:

- *Structuring positive interdependence within student learning groups*. Positive interdependence means that each student feels that he or she cannot succeed unless all the members of the group succeed. According to Johnson and Johnson, teachers create positive interdependence by making sure students have common goals and rewards, making students depend on other students for resources, assigning a role to each student in a group, and ensuring that tasks are equally divided.
- *Having students interact while completing assignments and ensuring that the interactions are on-task*. Interactions include student-to-student help and encouragement, explanations of ideas and problem-solving strategies, and discussions of other ideas related to the assignment.
- *Holding all students individually accountable for completing assignments and not letting them rely overly on the work of others*. Johnson and Johnson describe two strategies for holding students accountable: giving an individual test to each student rather than allowing group work on tests and randomly selecting one student's work to represent the work of the group.
- *Having students learn to use interpersonal and small group skills*. These skills include leadership, decision making, trust building, communication, and conflict management. Most high school students have never learned these skills, and unfortunately they are not commonly taught or practiced in high school. Many researchers and educators have published successful strategies for teaching interpersonal and small group skills.[41]
- *Ensuring that learning groups discuss how well the group functions*. When students receive feedback on their participation in the group, they can reflect on their roles and, if needed, adjust and adapt their social skills to help the group meet its objectives. Johnson and Johnson describe group processing as metacognitive thought about the functioning of the group.

Cooperative learning clearly places new demands on the teacher. The teacher must form effective groups, assign appropriate tasks, be keenly observant during group activities, diagnose problems quickly, and supply information or direction necessary to keep all groups moving forward. As with the other contextual teaching strategies, the teacher's role changes when he or she uses cooperative learning. The teacher is sometimes a lecturer, sometimes an observer, and sometimes a facilitator.[42]

Like the other contextual teaching strategies, cooperating is difficult but worth the additional effort if increasing student achievement is an important goal. Johnson and Johnson's research indicated that, when teachers use cooperating, their students' achievement increases significantly. Average students in cooperative classrooms were found to perform at much higher levels than average students in either competitive or individualistic classrooms. Specifically, students in the 50th percentile in cooperative classrooms were equivalent to students in the 71st percentile in competitive classrooms and equivalent to students in the 75th percentile in individualistic classrooms.[43] "In addition to the successful solution of math problems and the mastery and retention of math facts and principles, cooperative learning, compared with competitive and individualistic learning, promotes more frequent discovery and use of high-quality reasoning strategies, the generation of new ideas and solutions (that is, process gain), and the transferring of the math strategies and facts learned within the group to subsequent problems considered individually (that is, group-to-individual transfer)."[44]

> "Changes in the workplace increasingly demand teamwork, collaboration, and communication. Similarly, college-level mathematics courses are increasingly emphasizing the ability to convey ideas clearly, both orally and in writing. To be prepared for the future, high school students must be able to exchange mathematical ideas effectively with others."[45]
>
> National Council of Teachers of Mathematics

TRANSFERRING

In a traditional classroom, the teacher's primary role is to convey facts and procedures. The students' roles are to memorize the facts and practice the procedures by working skill drill exercises and, sometimes, word problems. Students who can recall and repeat the appropriate facts and procedures score well on the end-of-unit or end-of-semester test. By contrast, in a constructivist or contextual classroom, the teacher's role is expanded to include creating a variety of learning experiences with a focus on understanding rather than memorization. Contextual teachers use the strategies discussed above (relating, experiencing, applying, and cooperating) and they assign a wide variety of tasks to facilitate learning for understanding. In addition to skill drill and word problems, they assign experiential, hands-on activities and realistic problems through which students gain initial understanding and deepen their understanding of concepts.

Students who learn with understanding can also learn to transfer knowledge.[46] *Transferring* is a teaching strategy that we define as *using knowledge in a new context or novel situation—one that has not been covered in class.*

> "If students are expected to apply ideas in novel situations, then they must practice applying them in novel situations."[47]
>
> American Association for the Advancement of Science
> Project 2061

Research shows that, when teachers design tasks for novelty and variety, student interest, motivation, engagement, and mastery of mathematics goals can increase.[48] Excellent teachers seem to have a natural ability to introduce novel ideas that motivate students intrinsically by invoking curiosity or emotions. As an example of invoking emotion, a mathematics teacher with 16- and 17-year-old students could distribute a magazine article that uses statistics to argue that young people should not be allowed to obtain drivers' licenses until they are 18 years old. Predictably, many students will react emotionally to this argument. The resulting energy can be directed to engage the students in a discussion or debate, followed by a class assignment to work in groups to write critiques of the article. Critiques will include analysis of the mathematics. Were statistics misused? Were facts or assumptions misrepresented or omitted? Was the argument logical? If the critiques are persuasive, the teacher can even encourage students to submit them to the editor of the magazine as rebuttals.

Students also have natural curiosity about unfamiliar situations. A teacher can capitalize on student curiosity with problem-solving exercises such as the following.

> A sheet of notebook paper is approximately 2 mils thick. (A mil is one-thousandth of an inch.) If you fold a sheet of notebook paper in half, the total thickness is 4 mils. If you fold it in half again, the thickness becomes 8 mils. Suppose you could fold a sheet of notebook paper 50 times. Which of the following best describes the total thickness?
>
> a. Less than ten feet
> b. More than ten feet but less than a ten-story building
> c. More than a ten-story building but less than Mount Everest
> d. More than Mount Everest but less than the distance to the moon
> e. More than the distance to the moon

While folding a sheet of paper is not novel, students cannot be familiar with 50 folds because it is impossible to fold the paper that many times. The teacher encourages students in small groups to discuss the possible choices of thickness and then vote as groups for the choice they predict to be true. A spokesperson for each group explains the rationale for the prediction. After the votes are tallied on the board, students have "bought in" to the problem, and are eager to know the right answer. At this point, the teacher can have each student group find the thickness, without giving them a formula. The problem solution involves sequences, patterns, mathematical modeling, exponential functions, conversion factors, powers, and scientific notation. The solution is surprising, and the teacher can lead a class discussion of reasons most predictions are wrong, other situations where many doublings can occur, and the need for mathematics in these situations.

> ". . . A major goal of high school mathematics is to equip students with knowledge and tools that enable them to formulate, approach, and solve problems beyond those that they have studied."[49]
>
> National Council of Teachers of Mathematics

Excellent teachers use exercises like these to invoke curiosity and emotion as motivators in transferring mathematics ideas from one context to another. In addition, sensed meaning created by relating, experiencing, applying, cooperating, and transferring engages students' emotions. One of Caine and Caine's 12 Principles of Brain-Based Learning says, "Emotions and cognition cannot be separated and the conjunction of the two is at the heart of learning."[50] Although they did not use the term constructivism, their ideas about felt meaning, emotions, and cognition clearly paved the way: ". . . The brain needs to create its own meanings. Meaningful learning is built on creativity and is the source of much of the joy that students could experience in education."[51]

GRADUAL CHANGE

Creativity, joy, motivation, engagement, communication, and group processes are descriptors we often hear about our best teachers' classrooms. Our mission at CORD is to expand the use of contextual teaching and learning practices so that these descriptors will apply to more and more teachers' classrooms. But convincing teachers to change is very difficult.

Most teachers have natural tendencies to teach traditionally—the way they were taught, the way their teachers were taught, and so on. "Despite the dramatic transformations throughout our society over the last half-century, teaching methods in mathematics and science classes have remained virtually unchanged. Classroom practice has still hardly begun to capitalize on the many dimensions of the learning process."[52]

In addition, teaching contextually is not easy—it takes additional prep time and lots of hard work. Therefore, teachers must be motivated to devote the additional time and effort required to try the strategies and to persist when they encounter obstacles and difficulties. We have seen many teachers become highly motivated when they try a new strategy, experience success, and see positive changes in their students' level of engagement. We have found that motivation and successful implementation of contextual teaching and learning are usually the result of a gradual approach to change that combines long-term professional development, mentoring, collaboration with peers, practice, and reflection. CORD's most successful efforts have been through a 13-week professional development program centered on the REACT strategies. This program is delivered on the Internet, and teachers receive graduate credit for completing the course.

The REACT strategies are not the result of a single research project. Instead they are based on the most relevant research by educators, psychologists, and cognitive scientists and reinforced by observation of how the best teachers teach for understanding. CORD's professional development programs have demonstrated that the strategies can be learned and that, if they are introduced gradually and with support, teachers can be motivated to change. Most teachers, parents, and employers realize that no "silver bullets" will suddenly produce world-class learners in mathematics and science. Improving American students' performance in mathematics and science depends on improving mathematics and science teaching. And the key to improving teaching is a basic belief that better understanding of fundamental concepts will result in better test scores, not vice versa.

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